FINAL JEE(Advanced) EXAMINATION - 2019

(Held On Monday 27th MAY, 2019)

PAPER-2	TEST PAPER WITH ANSWER

PART-1 : PHYSICS

SECTION-1 : (Maximum Marks: 32)

- This section contains **EIGHT (08)** questions.
- Each question has **FOUR** options. **ONE OR MORE THAN ONE** of these four option(s) is (are) correct answer(s).
- For each question, choose the option(s) corresponding to (all) the correct answer(s)
- Answer to each question will be evaluated according to the following marking scheme:

  Full Marks : +4 If only (all) the correct option(s) is (are) chosen.
  Partial Marks : +3 If all the four options are correct but ONLY three options are chosen.
  Partial Marks : +2 If three or more options are correct but ONLY two options are chosen and both of which are correct.
  Partial Marks : +1 If two or more options are correct but ONLY one option is chosen and it is a correct option.
  Zero Marks : 0 If none of the options is chosen (i.e. the question is unanswered).
  Negative Marks : –1 In all other cases.
- For example, in a question, if (A), (B) and (D) are the ONLY three options corresponding to correct answers, then
  choosing ONLY (A), (B) and (D) will get +4 marks;
  choosing ONLY (A) and (B) will get +2 marks;
  choosing ONLY (A) and (D) will get +2 marks;
  choosing ONLY (B) and (D) will get +2 marks;
  choosing ONLY (A) will get +1 marks;
  choosing ONLY (B) will get +1 marks;
  choosing ONLY (D) will get +1 marks;
  choosing no option (i.e. the question is unanswered) will get 0 marks, and
  choosing any other combination of options will get –1 mark.

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1. A mixture of ideal gas containing 5 moles of monatomic gas and 1 mole of rigid diatomic gas is initially at pressure P_0, volume V_0 and temperature T_0. If the gas mixture is adiabatically compressed to a volume $V_0/4$, then the correct statement(s) is/are,

(Give $2^{1.2} = 2.3$; $2^{3.2} = 9.2$; R is gas constant)

(1) The final pressure of the gas mixture after compression is in between $9P_0$ and $10P_0$

(2) The average kinetic energy of the gas mixture after compression is in between $18RT_0$ and $19RT_0$

(3) The work |W| done during the process is $13RT_0$

(4) Adiabatic constant of the gas mixture is 1.6

Ans. (1,3,4)

Sol. $n_1 = 5$ moles $C_{V_1} = \frac{3R}{2}$ $\quad P_0V_0T_0$

$n_2 = 1$ mole $C_{V_2} = \frac{5R}{2}$

$$(C_V)_m = \frac{n_1C_{V_1} + n_2C_{V_2}}{n_1 + n_2} = \frac{5\times\frac{3R}{2} + 1\times\frac{5R}{2}}{6} = \frac{5R}{3}$$

$$\gamma_m = \frac{(c_P)_m}{(c_V)_m} = \frac{8}{5}$$

$\therefore$ Option 4 is correct

$$(C_P)_m = \frac{5R}{3} + R = \frac{8R}{3}$$

(1) $P_0V_0^\gamma = P\left(\frac{V_0}{4}\right)^\gamma \Rightarrow P = P_0(4)^{8/5} = 9.2\ P_0$ which is between $9P_0$ and $10P_0$

(2) Average K.E. $= 5 \times \frac{3}{2}RT + 1 \times \frac{5RT}{2}$

$= 10RT$

To calculate T

$$\frac{P_0V_0}{T_0} = 9.2P_0 \times \frac{V_0}{4\times T}$$

so $\qquad T = \frac{9.2}{4}T_0$

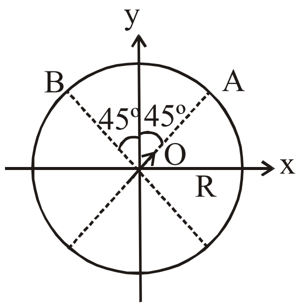
Now average KE $= 10\ R \times 9.2\ \frac{T_0}{4} = 23RT_0$

(3) $W = \frac{P_1V_1 - P_2V_2}{\gamma - 1}$

$$= \frac{P_0V_0 - 9.2P_0 \times \frac{V_0}{4}}{3/5} = -13RT_0$$

2. An electric dipole with dipole moment $\frac{p_0}{\sqrt{2}}(\hat{i}+\hat{j})$ is held fixed at the origin O in the presence of an uniform electric field of magnitude E_0. If the potential is constant on a circle of radius R centered at the origin as shown in figure, then the correct statement(s) is/are:

(ε_0 is permittivity of free space, R >> dipole size)



(1) $R=\left(\frac{p_0}{4\pi\varepsilon_0 E_0}\right)^{1/3}$

(2) The magnitude of total electric field on any two points of the circle will be same

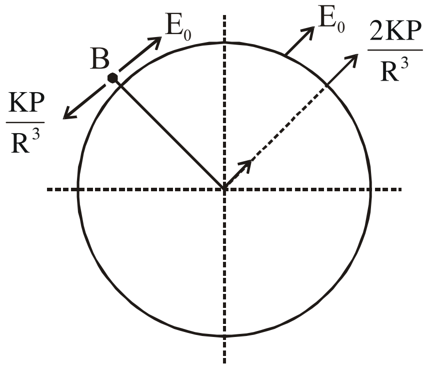
(3) Total electric field at point A is $\vec{E}_A=\sqrt{2}E_0(\hat{i}+\hat{j})$

(4) Total electric field at point B is $\vec{E}_B=0$

Ans. **(1,4)**

Sol. (1) $\vec{P}=\frac{P_0}{\sqrt{2}}\left(\hat{i}+\hat{j}\right)$

E.F. at B along tangent should be zero since circle is equipotential.



So, $E_0 = \frac{K|\vec{P}|}{R^3}$ & $E_B = 0$

So, $R^3 = \frac{KP_0}{E_0} = \left(\frac{P_0}{4\pi\in_0 E_0}\right)$

So $R = \left(\frac{P_0}{4\pi\in_0 E_0}\right)^{1/3}$

So, (1) is correct

(2) Because E_0 is uniform & due to dipole E.F. is different at different points, so magnitude of total E.F. will also be different at different points.

So, (2) is incorrect

(3) $E_A = \frac{2KP}{R^3} + \frac{KP}{R^3} = 3\frac{KP}{R^3}\frac{P_0}{\sqrt{2}}\left(\hat{i}+\hat{j}\right)$

So, (3) is wrong

(4) $E_B = 0$

so, (4) is correct

3. A thin and uniform rod of mass M and length L is held vertical on a floor with large friction. The rod is released from rest so that it falls by rotating about its contact-point with the floor without slipping. Which of the following statement(s) is/are correct, when the rod makes an angle 60º with vertical ? [g is the acceleration due to gravity]

(1) The radial acceleration of the rod's center of mass will be $\frac{3g}{4}$

(2) The angular acceleration of the rod will be $\frac{2g}{L}$

(3) The angular speed of the rod will be $\sqrt{\frac{3g}{2L}}$

(4) The normal reaction force from the floor on the rod will be $\frac{Mg}{16}$

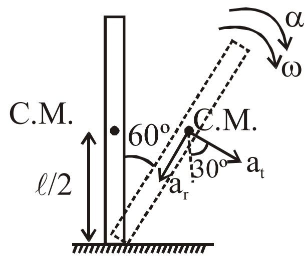
Ans. (1,3,4)

Sol. We can treat contact point as hinged.

Applying work energy theorem

$W_g = \Delta K.E.$

$$mg\frac{\ell}{4} = \frac{1}{2}\left(\frac{m\ell^2}{3}\right)\omega^2$$



$$\omega = \sqrt{\frac{3g}{2\ell}}$$

radial acceleration of C.M. of rod $= \left(\frac{\ell}{2}\right)\omega^2 = \frac{3g}{4}$

Using $\tau = I\,\alpha$ about contact point

$$\frac{mg\ell}{2}\sin 60° = \frac{m\ell^2}{3}\alpha$$

$$\Rightarrow \quad \alpha = \frac{3\sqrt{3}}{4\ell}g$$

Net vertical acceleration of C.M. of rod

$a_v = a_r \cos 60° + a_t \cos 30°$

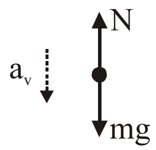
$$= \left(\frac{3g}{4}\right)\left(\frac{1}{2}\right) + \left(\alpha\frac{\ell}{2}\right)\cos 30°$$

$$= \frac{3g}{8} + \frac{3\sqrt{3}g}{4\ell}\left(\frac{\ell}{2}\right)\left(\frac{\sqrt{3}}{2}\right)$$

$$= \frac{3g}{8} + \frac{9g}{16} = \frac{15}{16}g$$

Applying F_{net} = ma in vertical direction on rod as system

$$mg - N = ma_v = m\left(\frac{15}{16}g\right)$$



$$\Rightarrow \quad N = \frac{mg}{16}$$

4. A small particle of mass m moving inside a heavy, hollow and straight tube along the tube axis undergoes elastic collision at two ends. The tube has no friction and it is closed at one end by a flat surface while the other end is fitted with a heavy movable flat piston as shown in figure. When the distance of the piston from closed end is $L = L_0$ the particle speed is $v = v_0$. The piston is moved inward at a very low speed V such that $V << \frac{dL}{L}v_0$, where dL is the infinitesimal displacement of the piston. Which of the following statement(s) is/are correct ?

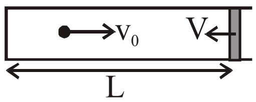
(1) The rate at which the particle strikes the piston is v/L

(2) After each collision with the piston, the particle speed increases by 2V

(3) The particle's kinetic energy increases by a factor of 4 when the piston is moved inward from L_0 to $\frac{1}{2}L_0$

(4) If the piston moves inward by dL, the particle speed increases by $2v\frac{dL}{L}$

Ans. (2,3)

Sol. 

(1) average rate of collision = $\frac{2L}{v}$

(2) speed of particle after collision = $2V + v_0$

change in speed = $(2V + v_0) - v_0$

after each collision = $2V$

no. of collision per unit time (frequency) = $\frac{v}{2L}$

change in speed in dt time = $2V \times$ number of collision in dt time

$$\Rightarrow dv = 2V\left(\frac{v}{2L}\right) \cdot \frac{dL}{V}$$

$$\boxed{dv = \frac{vdL}{L}}$$

Now, $dv = -\frac{vdL}{L}$ {as L decrease}

$$\int_{v_0}^{v} \frac{dv}{v} = -\int_{L_0}^{L_0/2} \frac{dL}{L}$$

$$\Rightarrow [\ln v]_{v_0}^{v} = -[\ln L]_{L}^{L_0/2}$$

$$\Rightarrow v = 2v_0$$

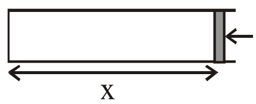
$$\Rightarrow KE_{L_0} = \frac{1}{2}mv_0^2$$

$$\boxed{\frac{KE_{L_0/2}}{KE_0} = 4}$$

$$KE_{L_0/2} = \frac{1}{2}m(2v_0)^2$$

or

$$(dt)\left(\frac{v}{2x}\right)\frac{2mv}{dt} = F$$



$$F = \frac{mv^2}{x}$$

$$-m\,v\,\frac{dv}{dx} = \frac{mv^2}{x}$$

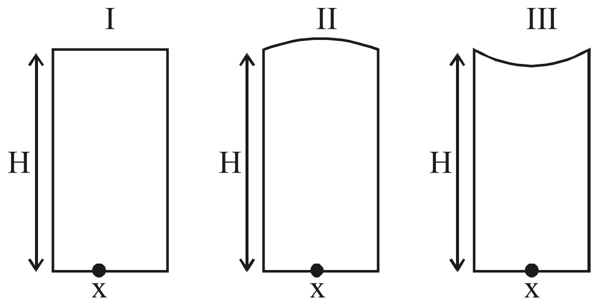
$$-\frac{dv}{v} = \frac{dx}{x}$$

$$\ln\frac{v_2}{v_1} = \ln\frac{x_1}{x_2}$$

vx = constant $\Rightarrow$ on decreasing length to half K.E. becomes 1/4

$vdx + xdv = 0$

5. Three glass cylinders of equal height H = 30 cm and same refractive index n = 1.5 are placed on a horizontal surfaces shown in figure. Cylinder I has a flat top, cylinder II has a convex top and cylinder III has a concave top. The radii of curvature of the two curved tops are same (R = 3m). If H_1, H_2 and H_3 are the apparent depths of a point X on the bottom of the three cylinders, respectively, the correct statement(s) is/are



(1) $H_3 > H_1$ (2) $0.8\text{ cm} < (H_2 - H_1) < 0.9\text{ cm}$

(3) $H_2 > H_3$ (4) $H_2 > H_1$

Ans. **(3,4)**

Sol. $H_1 = \dfrac{2H}{3} = \dfrac{2}{3} \times \dfrac{3}{10} = \dfrac{1}{5}\text{m}$

for 2[nd]

$$\frac{1}{v} + \frac{3}{2H} = \frac{-1}{2(-3)}$$

$$\frac{1}{v} = \frac{1}{6} - \frac{10}{2} = \frac{1}{6} - \frac{30}{6} = \frac{-29}{6}$$

$$H_2 = \frac{6}{29} > H_1$$

For 3[rd]

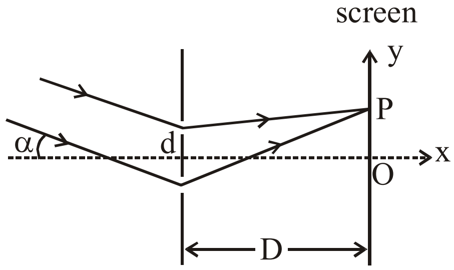
$$\frac{1}{v} + \frac{3}{2H} = \frac{-1}{2(3)}$$

$$\frac{1}{v} = \frac{-1}{6} - 5 = \frac{-31}{6}$$

$$H_3 = \frac{6}{31}$$

so $\boxed{H_3 < H_1 < H_2}$ & $(H_2 - H_1) = \dfrac{6}{29} - \dfrac{6}{31} = 0.68\,\text{cm}$

6. In a Young's double slit experiment, the slit separation d is 0.3 mm and the screen distance D is 1m. A parallel beam of light of wavelength 600nm is incident on the slits at angle α as shown in figure. On the screen, the point O is equidistant from the slits and distance PO is 11.0 mm. Which of the following statement(s) is/are correct ?



(1) For $\alpha = \frac{0.36}{\pi}$ degree, there will be destructive interference at point O.

(2) Fringe spacing depends on α

(3) For $\alpha = \frac{0.36}{\pi}$ degree, there will be destructive interference at point P

(4) For α = 0, there will be constructive interference at point P.

Ans. (3)

Sol. (1) $\Delta x = d\sin\alpha$

$= d\alpha$ (as α is very small) $\qquad \alpha = \frac{.36}{180} = (2\times10^{-3})\,\text{rad}$

$$\frac{\Delta x}{\lambda} = \frac{(3\times10^{-4})\,(2\times10^{-3})}{6\times10^{-7}} = 1$$

so constructive interference

(2) $\beta = \frac{D\lambda}{d}$

(3) $\Delta x_p = d\alpha + \frac{dy}{D}$

$= 3\times10^{-4}\,(2\times10^{-3} + 11\times10^{-3})$

$= 39\times10^{-7}$

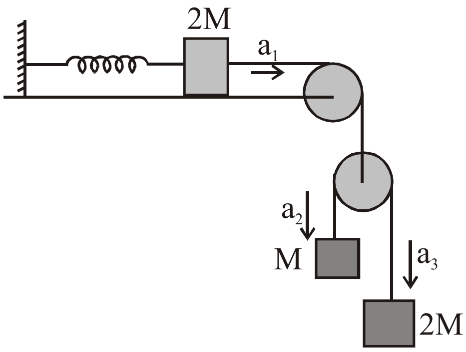
$$\frac{\Delta x_p}{\lambda} = \frac{39\times10^{-7}}{6\times10^{-7}} = 6.5 \text{ so destructive}$$

(4) $\Delta x_p = \frac{dy}{D} = (3\times10^{-4})\times11\times10^{-3}$

$= 33\times10^{-7}$

$$\frac{\Delta x_p}{\lambda} = \frac{33\times10^{-7}}{6\times10^{-7}} = 5.5 \Rightarrow \text{destructive}$$

7. A block of mass 2M is attached to a massless spring with spring-constant k. This block is connected to two other blocks of masses M and 2M using two massless pulleys and strings. The accelerations of the blocks are a_1, a_2 and a_3 as shown in figure. The system is released from rest with the spring in its unstretched state. The maximum extension of the spring is x_0. Which of the following option(s) is/are correct ? [g is the acceleration due to gravity. Neglect friction]



(1) $x_0 = \dfrac{4Mg}{k}$

(2) When spring achieves an extension of $\dfrac{x_0}{2}$ for the first time, the speed of the block connected to the spring is $3g\sqrt{\dfrac{M}{5k}}$

(3) $a_2 - a_1 = a_1 - a_3$

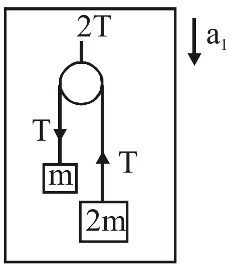
(4) At an extension of $\dfrac{x_0}{4}$ of the spring, the magnitude of acceleration of the block connected to the spring is $\dfrac{3g}{10}$

Ans. (3)

Sol.

$$\xrightarrow{\quad} a_1$$

$$kx \longleftarrow \boxed{2m} \longrightarrow 2T \qquad 2T - kx = 2ma_1$$



$T = \dfrac{2(2m)(m)}{3m}(g - a_1)$

$= \dfrac{4m}{3}(g - a_1)$

$\dfrac{8m}{3}(g - a_1) - kx = 2ma_1$

$$\frac{8Mg}{3}-\frac{8ma_1}{3}-kx=2ma_1$$

$$\frac{8Mg}{3}-kx=\frac{14ma_1}{3}$$

$$\frac{8Mg-3kx}{14m}=a_1$$

$$a_1 = \frac{8Mg-3kx}{14m}$$

$$\frac{vdv}{dx}=\left(\frac{8Mg}{14m}-\frac{3kx}{14m}\right)$$

$$\int vdv=\frac{1}{14m}\int(8Mg-3kx)dx$$

for max elongation

$$0 = \frac{1}{14m}\int_0^{x_0}(8Mg-3kx)dx$$

$$= \frac{1}{14m}\left(8Mgx_0-\frac{3kx_0^2}{2}\right)$$

$$8Mgx_0 = \frac{3kx_0^2}{2}$$

$$\boxed{x_0=\frac{16Mg}{3k}}$$

at $x = \frac{x_0}{2}$

$$\int_0^v vdv=\frac{1}{14m}\int_0^{x_0/2}(8Mg-3kx)dx$$

$$\frac{v^2}{2}=\frac{1}{14m}\left(\frac{8Mgx_0}{2}-\frac{3kx_0^2}{2\times4}\right)$$

$$v^2 = \frac{1}{7m}\left(\frac{8Mg}{2}\times\frac{16Mg}{3x}-\frac{3x}{8}\times\frac{16M^2g^2}{3x\times3x}\right)$$

$$= \frac{1}{7m}\left(\frac{64M^2g^2}{3x}-\frac{2M^2g^2}{3x}\right)$$

$$v^2 = \frac{62Mg^2}{21k}$$

For acc. $\boxed{2a_1=a_2+a_3}$ therefore

$a_2 - a_1 = a_1 - a_3$

$a_1 = \frac{8Mg - 3k\,x_0/4}{14m}$

$= \frac{8g}{14} - \frac{3kx_0}{14m \times 4}$

$= \frac{8g}{14} - \frac{3x}{14m \times 4} \times \frac{16Mg}{3x}$

$= \frac{8g}{14} - \frac{4g}{14}$

$= \frac{4g}{14} = \frac{2g}{7}$

OR

$\frac{8mg}{3} - \frac{8m}{3}a_1 - kx = 2ma_1$

$\frac{14m}{3}a_1 = -k\left[x - \frac{8mg}{3k}\right]$

$a_1 = -\frac{3k}{14m}\left[x - \frac{8mg}{3k}\right]$ ....(i)

that means, block 2m (connected with the spring) will perform SHM about $x_1 = \frac{8mg}{3k}$

therefore.

maximum elongation in the spring $x_0 = 2x_1 = \frac{16mg}{3k}$

on comparing equation (1) with

$a = -\omega^2 (x - x_0)$

$\omega = \sqrt{\frac{3k}{14m}}$

at $\left(\frac{x_0}{2}\right)$, block will be passing through its mean position therefore at mean position

$v_0 = A\omega = \frac{8mg}{3k}.\sqrt{\frac{3k}{14m}}$

At, $\frac{x_0}{4} \Rightarrow x = \frac{A}{2}$

$\therefore\ a_{cc} = -\frac{A}{2}\omega^2$

$= -\frac{4mg}{3k}.\frac{3h}{14m} = -\frac{2g}{7}$

8. A free hydrogen atom after absorbing a photon of wavelength λ_a gets excited from the state n = 1 to the state n = 4. Immediately after that the electron jumps to n = m state by emitting a photon of wavelength λ_e. Let the change in momentum of atom due to the absorption and the emission are Δp_a and Δp_e , respectively. If $\lambda_a/\lambda_e = \frac{1}{5}$. Which of the option(s) is/are correct ?

[Use hc = 1242 eV nm; 1 nm = 10^{-9} m, h and c are Planck's constant and speed of light, respectively]

(1) λ_e = 418 nm

(2) The ratio of kinetic energy of the electron in the state n = m to the state n = 1 is $\frac{1}{4}$

(3) m = 2

(4) $\Delta p_a/\Delta p_e = \frac{1}{2}$

Ans. (2,3)

Sol. $$\frac{hc}{\lambda_a} = 13.6\left[\frac{1}{1} - \frac{1}{4^2}\right] \qquad ...(i)$$

$$\frac{hc}{\lambda_e} = 13.6\left[\frac{1}{m^2} - \frac{1}{4^2}\right] \qquad ...(ii)$$

(ii) / (i) , we get

$$\frac{\lambda_a}{\lambda_e} = \frac{\left[\frac{1}{m^2} - \frac{1}{16}\right]}{\left[1 - \frac{1}{16}\right]} = \frac{1}{5}$$

$$\Rightarrow \frac{1}{m^2} - \frac{1}{16} = \frac{15}{16} \times \frac{1}{5}$$

$$\Rightarrow \frac{1}{m^2} - \frac{1}{16} = \frac{3}{16}$$

$$\Rightarrow \frac{1}{m^2} = \frac{3}{16} + \frac{1}{16}$$

$$\Rightarrow \boxed{m = 2}$$

from (ii)

$$\frac{hc}{\lambda_e} = 13.6\left[\frac{1}{2^2} - \frac{1}{4^2}\right] = 13.6 \times \frac{3}{16} \text{ev}$$

$$\Rightarrow \lambda_e = \frac{12400 \times 16}{13.6 \times 3} \text{Å}$$

$\Rightarrow \quad \lambda_e \approx 4862 Å$

we have $KE_n \propto \frac{z^2}{n^2}$

$\Rightarrow \frac{KE_2}{KE_1} = \frac{1}{4}$

$\Delta P_a = \frac{h}{\lambda_a}$

$\Delta P_e = \frac{h}{\lambda_e}$

$\Rightarrow \frac{\Delta P_a}{\Delta P_e} = \frac{\lambda_e}{\lambda_a}$

SECTION-2 : (Maximum Marks: 18)

- This section contains **SIX (06)** questions. The answer to each question is a **NUMERICAL VALUE**.
- For each question, enter the correct numerical value of the answer using the mouse and the on-screen virtual numeric keypad in the place designated to enter the answer. If the numerical value has more than two decimal places, **truncate/round-off** the value to **Two** decimal places.
- Answer to each question will be evaluated according to the following marking scheme:

Full Marks : +3 If ONLY the correct numerical value is entered.

Zero Marks : 0 In all other cases.

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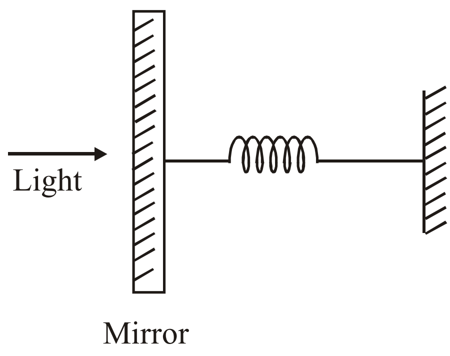
1. A perfectly reflecting mirror of mass M mounted on a spring constitutes a spring-mass system of angular frequency Ω such that $\frac{4\pi M\Omega}{h} = 10^{24} m^{-2}$ with h as Planck's constant. N photons of wavelength $\lambda = 8\pi \times 10^{-6}$m strike the mirror simultaneously at normal incidence such that the mirror gets displaced by 1μm. If the value of N is $x \times 10^{12}$, then the value of x is________.

[Consider the spring as massless]



Ans. (1.00)

Sol. Let momentum of one photon is p and after reflection velocity of the mirror is v.

conservation of linear momentum

$$N p\hat{i} = -Np\hat{i} + mv\hat{i}$$

$$mv\hat{i} = 2pN\hat{i}$$

$$mv = 2Np \qquad ....(1)$$

since v is velocity of mirror (spring mass system) at mean position,

$$v = A\Omega$$

Where A is maximum deflection of mirror from mean position. (A = 1 μm) and Ω is angular frequency of mirror spring system,

momentum of 1 photon, $p = \dfrac{h}{\lambda}$

$$mv = 2Np \qquad .....(i)$$

$$mA\Omega = 2N\frac{h}{\lambda}$$

$$N = \frac{m\Omega}{h} \times \frac{\lambda A}{2}$$

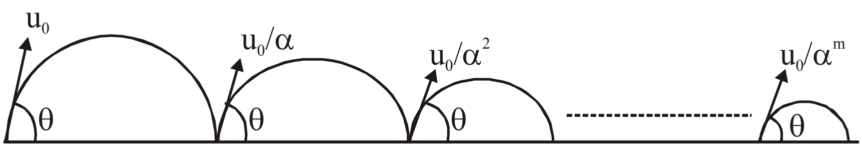
given, $\dfrac{m\Omega}{h} = \dfrac{10^{24}}{4\pi} m^{-2}$

$$\lambda = 8\pi \times 10^{-6} \text{ m}$$

$$N = \frac{10^{24}}{4\pi} \times \frac{8\pi \times 10^{-6} \times 10^{-6}}{2}$$

$$N = 10^{12} = x \times 10^{12}$$

2. A ball is thrown from ground at an angle θ with horizontal and with an initial speed u_0. For the resulting projectile motion, the magnitude of average velocity of the ball up to the point when it hits the ground for the first time is V_1. After hitting the ground, ball rebounds at the same angle θ but with a reduced speed of u_0/α. Its motion continues for a long time as shown in figure. If the magnitude of average velocity of the ball for entire duration of motion is 0.8 V_1, the value of α is______



Ans. (4.00)

Sol. $\underset{<v>}{\text{Average velocity}} = \dfrac{\text{Total displacement}}{\text{Total time}}$

Total time taken = $t_1 + t_2 + t_3 + \ldots\ldots\ldots\ldots\ldots$

$= t_1 + \dfrac{t_1}{\alpha} + \dfrac{t_1}{\alpha^2} + \ldots\ldots\ldots\ldots$

Total time = $\dfrac{t_1}{1-\dfrac{1}{\alpha}}$

Total displacement = $v_1t_1 + v_2t_2 + \ldots\ldots\ldots\ldots$

$= v_1t_1 + \dfrac{v_1}{\alpha}.\dfrac{t_1}{\alpha} + \ldots\ldots\ldots\ldots$

$= \dfrac{v_1t_1}{1-\dfrac{1}{\alpha^2}}$

On solving

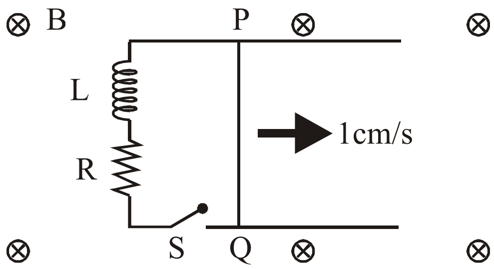
$<v> = \dfrac{v_1\alpha}{\alpha+1} = 0.8v_1$

$\boxed{\alpha = 4.00}$

3. A 10 cm long perfectly conducting wire PQ is moving, with a velocity 1cm/s on a pair of horizontal rails of zero resistance. One side of the rails is connected to an inductor L = 1 mH and a resistance $R = 1\Omega$ as shown in figure. The horizontal rails, L and R lie in the same plane with a uniform magnetic field B = 1 T perpendicular to the plane. If the key S is closed at certain instant, the current in the circuit after 1 millisecond is $x \times 10^{-3}$A, where the value of x is_______.

[Assume the velocity of wire PQ remains constant (1 cm/s) after key S is closed.

Given : $e^{-1} = 0.37$, where e is base of the natural logarithm]



Ans. (0.63)

Sol. Since velocity of PQ is constant. So emf developed across it remains constant.

$\varepsilon = Blv$ where ℓ = length of wire PQ

Current at any time t is given by

$$i = \frac{\varepsilon}{R}\left(1 - e^{-\frac{Rt}{L}}\right)$$

$$i = \frac{B\ell v}{R}(1 - e^{-\frac{Rt}{L}})$$

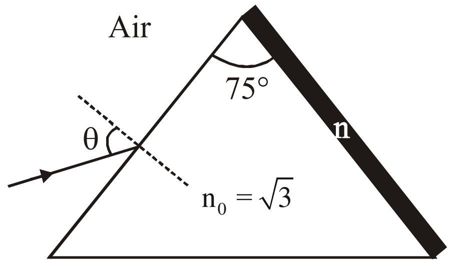
$$= 1\times\left(\frac{10}{100}\right)\times\left(\frac{1}{100}\right)\times\frac{1}{1}\left(1-e^{\frac{-1\times10^{-3}}{1\times10^{-3}}}\right)$$

$$= \frac{1}{1000}\times(1-e^{-1})$$

$$= \frac{1}{1000}\times(1-0.37)$$

$i = 0.63 \times 10^{-3}$ A $\Rightarrow x = 0.63$

4. A monochromatic light is incident from air on a refracting surface of a prism of angle 75° and refractive index $n_0 = \sqrt{3}$. The other refracting surface of a prism is coated by a thin film of material of refractive index n as shown in figure. The light suffers total internal reflection at the coated prism surface for an incidence angle of $\theta \le 60°$. The value of n^2 is_______.

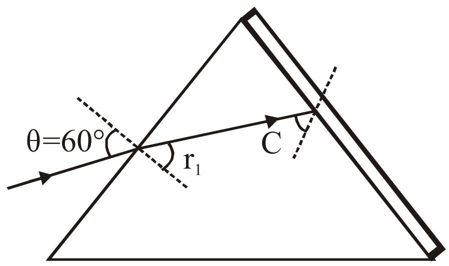


Ans. (1.50)

Sol. At θ = 60° ray incidents at critical angle at second surface

So,

$\sin\theta = \sqrt{3}\ \sin r_1$



$$\frac{\sqrt{3}}{2} = \sqrt{3}\sin r_1$$

$r_1 = 30°$

$r_2 = 45° = C$

$$\sqrt{3}\sin 45° = n\sin 90°$$

$$n = \sqrt{\frac{3}{2}} \Rightarrow n^2 = \frac{3}{2}$$

5. Suppose a $^{226}_{88}Ra$ nucleus at rest and in ground state undergoes α-decay to a $^{222}_{86}Rn$ nucleus in its excited state. The kinetic energy of the emitted α particle is found to be 4.44 MeV. $^{222}_{86}Rn$ nucleus then goes to its ground state by γ-decay. The energy of the emitted γ-photon is _______ keV,

[Given: atomic mass of $^{226}_{88}Ra = 226.005u$, atomic mass of $^{222}_{86}Rn = 222.000u$, atomic mass of α particle = 4.000u, 1u = 931 MeV/c^2, c is speed of the light]

Ans. (135.00)

Sol. $Ra^{226} \longrightarrow Rn^{222} + \alpha$

Q = (226.005 – 222–4) 931 MeV

= 4.655 MeV

$K_\alpha = \frac{A-4}{A}(Q - E_\gamma)$

4.44 MeV = $\frac{222}{226}(Q - E_\gamma)$

Q – E_γ = $(4.44)\left(\frac{226}{222}\right)$MeV

E_γ = 4.655 – 4.520

= .135 MeV

= 135 KeV

6. An optical bench has 1.5 m long scale having four equal divisions in each cm. While measuring the focal length of a convex lens, the lens is kept at 75 cm mark of the scale and the object pin is kept at 45 cm mark. The image of the object pin on the other side of the lens overlaps with image pin that is kept at 135 cm mark. In this experiment, the percentage error in the measurement of the focal length of the lens is________.

Ans. (0.69)

Sol. For the given lens

u = –30 cm

v = 60 cm

& $\frac{1}{f} = \frac{1}{v} - \frac{1}{u}$ on solving : f = 20 cm

also $\frac{1}{f} = \frac{1}{v} - \frac{1}{u}$

on differentiation

$$\frac{df}{f^2} = \frac{dv}{v^2} + \frac{du}{u^2}$$

$$\frac{df}{f} = f\left[\frac{dv}{v^2} + \frac{du}{u^2}\right]$$

& $\frac{df}{f} \times 100 = f\left[\frac{dv}{v^2} + \frac{du}{u^2}\right] \times 100\%$

f = 20cm, du = dv = $\frac{1}{4}$cm

Since there are 4 divisions in 1 cm on scale

$$\therefore \frac{df}{f}\times 100 = 20\left[\frac{1/4}{(60)^2}+\frac{1/4}{(30)^2}\right]\times 100\%$$

$$= 5\left[\frac{1}{3600}+\frac{1}{900}\right]\times 100\%$$

$$= 5\left[\frac{5}{36}\right]\% = \frac{25}{36}\% \approx 0.69\%$$

SECTION–3 : (Maximum Marks : 12)

- This section contains **TWO (02)** List-Match sets.
- Each List-Match set has **Two (02)** Multiple Choice Questions.
- Each List-Match set has two lists : **List-I** and **List-II**
- **List-I** has **Four** entries (I), (II), (III) and (IV) and **List-II** has **Six** entries (P), (Q), (R), (S), (T) and (U)
- **FOUR** options are given in each Multiple Choice Question based on **List-I** and **List-II** and **ONLY ONE** of these four options satisfies the condition asked in the Multiple Choice Question.
- Answer to each question will be evaluated according to the following marking scheme :

Full Marks	: +3	If ONLY the option corresponding to the correct combination is chosen.
Zero Marks	: 0	If none of the options is chosen (i.e., the question is unanswered);
Negative Marks	: –1	In all other cases

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1. Answer the following by appropriately matching the lists based on the information given in the paragraph.

A musical instrument is made using four different metal strings, 1,2,3 and 4 with mass per unit length μ, 2μ, 3μ and 4μ respectively. The instrument is played by vibrating the strings by varying the free length in between the range L_0 and $2L_0$. It is found that in string-1 (μ) at free length L_0 and tension T_0 the fundamental mode frequency is f_0.

List-I gives the above four strings while list-II lists the magnitude of some quantity.

List-I	**List-II**
(I) String-1(μ)	(P) 1
(II) String-2 (2μ)	(Q) 1/2
(III) String-3 (3μ)	(R) $1/\sqrt{2}$
(IV) String-4 (4μ)	(S) $1/\sqrt{3}$
	(T) 3/16
	(U) 1/16

If the tension in each string is T_0, the correct match for the highest fundamental frequency in f_0 units will be,

(1) I→P, II→R, III→S, IV→Q

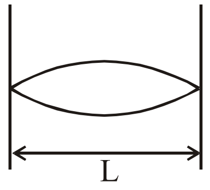
(2) I→P, II→Q, III→T, IV→S

(3) I→Q, II→S, III→R, IV→P

(4) I→Q, II→P, III→R, IV→T

Ans. (1)

Sol. For fundamental mode



$$\frac{\lambda}{2} = L \quad \Rightarrow \lambda = 2L$$

$$f = \frac{V}{\lambda} = \frac{1}{2L}\sqrt{\frac{T}{\mu}}$$

For string (1)

$$f_0 = \frac{1}{2L}\sqrt{\frac{T}{\mu}} \quad \Rightarrow (P)$$

For string (2)

$$f = \frac{1}{2L}\sqrt{\frac{T}{2\mu}} = \frac{f_0}{\sqrt{2}} \Rightarrow (R)$$

For string (3)

$$f = \frac{1}{2L}\sqrt{\frac{T}{3\mu}} = \frac{f_0}{\sqrt{3}} \Rightarrow (S)$$

For string (4)

$$f = \frac{1}{2L}\sqrt{\frac{T}{4\mu}} = \frac{f_0}{2} \Rightarrow (Q)$$

2. Answer the following by appropriately matching the lists based on the information given in the paragraph.

A musical instrument is made using four different metal strings, 1,2,3 and 4 with mass per unit length μ, 2μ, 3μ and 4μ respectively. The instrument is played by vibrating the strings by varying the free length in between the range L_0 and $2L_0$. It is found that in string-1 (μ) at free length L_0 and tension T_0 the fundamental mode frequency is f_0.

List-I gives the above four strings while list-II lists the magnitude of some quantity.

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(II) String-2 (2μ)	(Q) 1/2
(III) String-3 (3μ)	(R) $1/\sqrt{2}$
(IV) String-4 (4μ)	(S) $1/\sqrt{3}$
	(T) 3/16
	(U) 1/16

The length of the string 1,2,3 and 4 are kept fixed at $L_0, \frac{3L_0}{2}, \frac{5L_0}{4}$ and $\frac{7L_0}{4}$, respectively. Strings 1,2,3 and 4 are vibrated at their 1st, 3rd, 5th and 14th harmonics, respectively such that all the strings have same frequency. The correct match for the tension in the four strings in the units of T_0 will be.

(1) I→P, II→Q, III→T, IV→U

(2) I→T, II→Q, III→R, IV→U

(3) I→P, II→Q, III→R, IV→T

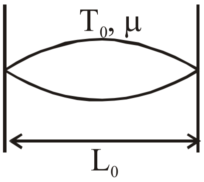
(4) I→P, II→R, III→T, IV→U

Ans. **(1)**

Sol. For string (1)

Length of string = L_0

It is vibrating in Ist harmonic i.e. fundamental mode.



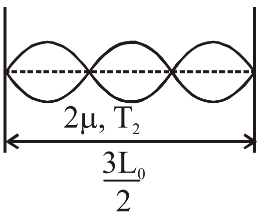
$$f_0 = \frac{1}{2L_0}\sqrt{\frac{T_0}{\mu}} \Rightarrow (P)$$

For string (2)

Length of string = $\frac{3L_0}{2}$

It is vibrating in IIIrd harmonic but frequency is still f_0.

$$f_0 = \frac{3v}{2L}$$



$$f_0 = \frac{3}{2\left(\frac{3L_0}{2}\right)}\sqrt{\frac{T_2}{2\mu}}$$

$$\Rightarrow f_0 = \frac{1}{L_0}\sqrt{\frac{T_2}{2\mu}} = \frac{1}{2L_0}\sqrt{\frac{T_0}{\mu}}$$

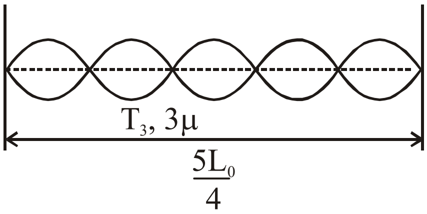
$$\Rightarrow \boxed{T_2 = \frac{T_0}{2}} \Rightarrow (Q)$$

For string (3)

Length of string = $\frac{5L_0}{4}$

It is vibrating in 5^{th} harmonic but frequency is still f_0.

$$f_0 = \frac{5V}{2L}$$



$$\Rightarrow f_0 = \frac{5}{2\left(\frac{5L_0}{4}\right)}\sqrt{\frac{T_3}{3\mu}} = \frac{1}{2L_0}\sqrt{\frac{T_0}{\mu}}$$

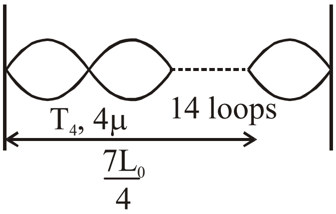
$$\Rightarrow \frac{2}{L_0}\sqrt{\frac{T_3}{3\mu}} = \frac{1}{2L_0}\sqrt{\frac{T_0}{\mu}}$$

$$T_3 = \frac{3T_0}{16} \Rightarrow (T)$$

For string (4)

Length of string = $\frac{7L_0}{4}$

It is vibrating in 14^{th} harmonic but frequency is still f_0.



$$f_0 = \frac{14v}{2L}$$

$$\Rightarrow \quad f_0 = \frac{14}{2\left(\frac{7L_0}{4}\right)}\sqrt{\frac{T_4}{4\mu}} = \frac{1}{2L_0}\sqrt{\frac{T_0}{\mu}}$$

$$\Rightarrow \frac{4}{L_0}\sqrt{\frac{T_4}{4\mu}} = \frac{1}{2L_0}\sqrt{\frac{T_0}{\mu}} \Rightarrow \boxed{T_4 = \frac{T_0}{16}} \Rightarrow (U)$$

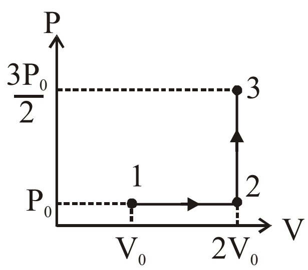
3. Answer the following by appropriately matching the lists based on the information given in the paragraph.

In a thermodynamics process on an ideal monatomic gas, the infinitesimal heat absorbed by the gas is given by $T\Delta X$, where T is temperature of the system and ΔX is the infinitesimal change in a thermodynamic quantity X of the system. For a mole of monatomic ideal gas $X = \frac{3}{2}R\ln\left(\frac{T}{T_A}\right) + R\ln\left(\frac{V}{V_A}\right)$. Here, R is gas constant, V is volume of gas, T_A and V_A are constants.

The List-I below gives some quantities involved in a process and List-II gives some possible values of these quantities.

List-I	List-II
(I) Work done by the system in process $1 \to 2 \to 3$	(P) $\frac{1}{3}RT_0 \ln 2$
(II) Change in internal energy in process $1 \to 2 \to 3$	(Q) $\frac{1}{3}RT_0$
(III) Heat absorbed by the system in process $1 \to 2 \to 3$	(R) RT_0
(IV) Heat absorbed by the system in process $1 \to 2$	(S) $\frac{4}{3}RT_0$
	(T) $\frac{1}{3}RT_0(3+\ln 2)$
	(U) $\frac{5}{6}RT_0$

If the process carried out on one mole of monatomic ideal gas is as shown in figure in the PV-diagram with $P_0V_0 = \frac{1}{3}RT_0$, the correct match is,



(1) I $\to$ Q, II $\to$ R, III $\to$ P, IV $\to$ U

(2) I $\to$ S, II $\to$ R, III $\to$ Q, IV $\to$ T

(3) I $\to$ Q, II $\to$ R, III $\to$ S, IV $\to$ U

(4) I $\to$ Q, II $\to$ S, III $\to$ R, IV $\to$ U

Ans. (3)

Sol. (I) Degree of freedom f = 3

Work done in any process = Area under P–V graph

$\Rightarrow$ Work done in $1 \to 2 \to 3 = P_0V_0$

$$= \frac{RT_0}{3} \Rightarrow (Q)$$

(II) Change in internal energy $1 \to 2 \to 3$

$$\Delta U = nC_v\Delta T$$

$$= \frac{f}{2}nR\Delta T$$

$$= \frac{f}{2}\left(P_fV_f - P_iV_i\right)$$

$$= \frac{3}{2}\left(\frac{3P_0}{2}2V_0 - P_0V_0\right)$$

$$= 3P_0V_0$$

$$\Delta U = RT_0 \Rightarrow (R)$$

(III) Heat absorbed in $1 \to 2 \to 3$

for any process, Ist law of thermodynamics

$$\Delta Q = \Delta W + \omega$$

$$\Delta Q = RT_0 + \frac{RT_0}{3}$$

$$\Delta Q = \frac{4RT_0}{3} \Rightarrow (S)$$

(IV) Heat absorbed in process $1 \to 2$

$$\Delta Q = \Delta U + W$$

$$= \frac{f}{2}\left(P_fV_f - P_iV_i\right) + W$$

$$= \frac{3}{2}\left(P_02V_0 - P_0V_0\right) + P_0V_0$$

$$= \frac{5}{2}P_0V_0$$

$$= \frac{5}{2}\left(\frac{RT_0}{3}\right)$$

$$\boxed{\Delta Q = \frac{5RT_0}{6}} \Rightarrow (U)$$

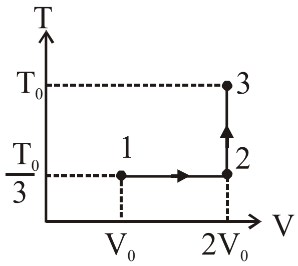
4. **Answer the following by appropriately matching the lists based on the information given in the paragraph.**

In a thermodynamic process on an ideal monatomic gas, the infinitesimal heat absorbed by the gas is given by $T\Delta X$, where T is temperature of the system and ΔX is the infinitesimal change in a thermodynamic quantity X of the system. For a mole of monatomic ideal gas $X = \frac{3}{2}R\ln\left(\frac{T}{T_A}\right) + R\ln\left(\frac{V}{V_A}\right)$. Here, R is gas constant, V is volume of gas, T_A and V_A are constants.

The List-I below gives some quantities involved in a process and List-II gives some possible values of these quantities.

List-I	**List-II**
(I) Work done by the system in process $1 \rightarrow 2 \rightarrow 3$	(P) $\frac{1}{3}RT_0 \ln 2$
(II) Change in internal energy in process $1 \rightarrow 2 \rightarrow 3$	(Q) $\frac{1}{3}RT_0$
(III) Heat absorbed by the system in process $1 \rightarrow 2 \rightarrow 3$	(R) RT_0
(IV) Heat absorbed by the system in process $1 \rightarrow 2$	(S) $\frac{4}{3}RT_0$
	(T) $\frac{1}{3}RT_0(3+\ln 2)$
	(U) $\frac{5}{6}RT_0$

If the process on one mole of monatomic ideal gas is an shown is as shown in the TV-diagram with $P_0V_0 = \frac{1}{3}RT_0$, the correct match is



(1) I $\rightarrow$ S, II $\rightarrow$ T, III $\rightarrow$ Q, IV $\rightarrow$ U

(2) I $\rightarrow$ P, II $\rightarrow$ R, III $\rightarrow$ T, IV $\rightarrow$ S

(3) I $\rightarrow$ P, II $\rightarrow$ T, III $\rightarrow$ Q, IV $\rightarrow$ T

(4) I $\rightarrow$ P, II $\rightarrow$ R, III $\rightarrow$ T, IV $\rightarrow$ P

Ans. (4)

Sol. Process $1 \rightarrow 2$ is isothermal (temperature constant)

Process $2 \rightarrow 3$ is isochoric (volume constant)

(I) Work done in $1 \rightarrow 2 \rightarrow 3$

$W = W_{1\rightarrow 2} + W_{2\rightarrow 3}$

$$= nRT \ln \left(\frac{V_f}{V_i}\right) + W_{2\rightarrow 3}$$

$$= \frac{RT_0}{3} \ln\left(\frac{2V_0}{V_0}\right) + 0$$

$$W = \frac{RT_0}{3} \ln 2 \quad \Rightarrow (P)$$

(II) ΔU in $1 \rightarrow 2 \rightarrow 3$

$$\Delta U = \frac{f}{2} nR (T_f - T_i)$$

$$= \frac{3}{2} R\left(T_0 - \frac{T_0}{3}\right)$$

$$= \frac{3}{2} R\left(\frac{2T_0}{3}\right)$$

$$\boxed{\Delta U = RT_0} \quad \Rightarrow (R)$$

(III) For any system, first law of thermodynamics for $1 \rightarrow 2 \rightarrow 3$

$\Delta Q = \Delta U + W$

$$\Delta Q = RT_0 + \frac{RT_0}{3} \ln 2$$

$$\Delta Q = \frac{RT_0}{3} (3 + \ln 2) \Rightarrow (T)$$

(IV) For process $1 \rightarrow 2$ (isothermal)

$\Delta Q = \Delta U + W$

$$= \frac{f}{2} nR(T_f - T_i) + nRT \ln (V_f / V_i)$$

$$= 0 + R\left(\frac{T_0}{3}\right) \ln\left(\frac{2v_0}{v_0}\right)$$

$$\boxed{\Delta Q = \frac{RT_0}{3} \ln 2} \quad \Rightarrow (P)$$